Original Article

Modeling the Distribution of Dominant Hard Ticks in Southeastern Coastal Areas of the Caspian Sea

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Abstract

Background: Ticks are hematophagous arthropods that have direct and indirect effects on hosts, including the transmission of pathogens. An environmental suitability study of some vector species of hard ticks was conducted using the MaxEnt model in the south-eastern region of the Caspian Sea in Iran.

Methods: The ticks were collected monthly (2014─2015) at 45 study sites covering different areas in terms of topography. Because most farms in the study area are traditionally engaged in sheep production and they are taken to pastures in the warm season, the ticks were sampled from herds of sheep.

Results: In total, 2410 hard ticks were collected and the vector species with wider distributions were considered for modelling. The areas under the curve for *Hyalomma anatulicum*, *Hy. asiaticum*, *Hy. marginatum*, *Rhipicephalus bursa*, *Rh. sanguineus*, and *Rh. turanicus* were 0.848, 0.762, 0.812, 0.772, 0.770 and 0.803, respectively. This means that temperature and precipitation were effective environmental variables for the prediction of appropriate regions for these tick species. The outputs of the models indicated that the western and south- western regions of Golestan Province provided the best niches for the presence of ticks.

Conclusion: The western regions of Golestan Province are potential habitats for tick-borne diseases in both livestock and humans and special attention should be focused on preventing the spread of such diseases in this region.

Keywords: Ticks; Ixodidae; Ecological niche modeling; MaxEnt; Iran

Introduction

Ticks are ectoparasites that require the blood of animals and humans for survival. This makes them significant public health threats to humans and farm animals (1). Ticks can injure the skin, reduce livestock production, and increase transmission of parasitic, bacterial, and viral infections (2─4). The health threat to humans and livestock posed by tick infestations are global concern.

Ticks (Arachnida: Parasitiformes) include two families in Iran: Ixodidae (hard ticks) and Argasidae (soft ticks) (5). In the family Ixodidae, the genera of veterinary importance are *Rhipicephalus*, *Amblyomma*, *Haemaphysalis*, *Hyalomma*, *Dermacentor*, and *Ixodes* (6). The genus *Hyalomma* includes thirty species that inhabit the Palearctic, Oriental, and Afrotropical Regions (7).

Hyalomma anatulicum is an important veterinary parasite that can be found in regions from Africa to India that feed on cattle, sheep, goats, camels, horses, and donkeys. This tick species transmits a variety of infectious agents to animals and humans, including *Theileria annulata*, *T. lestoquardi*, *T. equi*, *Babesia caballi*, *Trypanosoma theileri*, *Anaplasma* spp., *Francisella tularensis*, *Ehrlichia* and CCHF virus (8−16).

Since 1999, many cases of Crimean-Congo fever have been diagnosed in humans in Iran (17), especially in Golestan Province (18). *Hyalomma anatulicum* is the most widespread species in Iran. This tick species has been collected from all zoogeographic conditions, including arid, temperate, and mountainous areas and even from the Persian Gulf Islands (such as Qeshm Island). Previous studies have emphasized that *Hy. anatulicum* is most widely distributed in arid or semi-desert areas (19−21).

Several environmental variables (both biotic and abiotic), such as climatic and meteorological conditions, are known to influence ticks and tick-borne pathogens (22−28). Information about tick frequency and distribution, along with the prevalence of tick-borne infections, are essential components when developing public health policies against such pathogens.

A large outlay of time and money is required to collect data from the field, even on a small scale. In this regard, modelling can help to overcome these challenges (29). Modelling the distribution of the species in the spread of vector-borne diseases is important from the epidemiological perspective. It is first necessary to determine which areas offer favourable environmental and climatic conditions for the presence and breeding of a given vector to determine methods of preventing exposure to or controlling the species (30).

Several methods exist for modelling the environmental suitability of a species. Maximum entropy (MaxEnt), which uses presence-only data for predicting the ecological niches of species, is an example of these methods. Although some species distribution models (SDMs) use presence/absence data of species for modelling, previous studies by the authors on modelling only had access to the presence of a species. With the use of available historical data, a specific species can be predicted to exist at a specific location but cannot be confirmed to be absent in a nearby location. The MaxEnt model has become increasingly popular because of the existence of extensive historical data for modelling studies (31). MaxEnt can be used to find hotspots of a particular species within its habitat and to predict suitable environmental conditions for the species outside its current habitat (32).

In Iran, the first studies on ticks were carried out in 1936 and they have continued throughout the country (20, 33−39). In the northern part of Iran, tick fauna has been intensively investigated (40−45). However, no modelling study has been conducted on the prevalence and prediction of ticks and their outbreaks in different geographical locations in Iran.

The present study was undertaken to predict suitable environmental conditions for the dominant hard tick species of veterinary importance in Golestan Province, as a nexus of animal husbandry in north-eastern Iran.

Materials and Methods

Study region

Golestan Province is situated on the eastern edge of the Caspian Sea (Fig. 1). This province is divided into three topographical areas (mountains, plains, and coasts), with a mild humid climate. The average annual minimum and maximum air temperatures at meteorological stations are 12.2 °C and 25.8 °C, respectively, with an average relative humidity of 40–92%.

Many areas in the eastern and north-eastern parts of Golestan Province feature a dry climate. This means that the density of livestock in these areas is less than in the western and central parts of the province. Furthermore, the vegetation is richer in the western and southern parts of this province than in the eastern parts.

Tick collection and database development

The ticks were collected monthly (from October 2014 to December 2015) at 45 study sites in Golestan Province (Fig. 1). In each of the three regions (hillside, plain, and coastal areas of Golestan Province), 15 farms to the west, east, north, and south that were equidistant from the centre of the province were selected. In each, a flock of sheep that had fed on free pasture was chosen for tick collection. The tick samples were collected from the whole body of infested sheep using curved forceps, preserved in 70% alcohol, and identified morphologically using the identification keys (8, 46).

The coordinates of the sampling location were determined with a GPS device. The data collected and tick identification results were noted into an Excel file and converted to CSV format for modelling in MaxEnt. A geodatabase of Ixodid ticks was developed in Excel using the data obtained from this study.

Model variables

The WorldClim database was used for bioclimatic (Table 1) and altitude variables, which was downloaded with a spatial resolution of 1 km^2 (47). The bioclimatic data were due to the historical (near current) database. The Normalized Difference Vegetation Index (NDVI) was acquired from the June 2016 image of the MODIS satellite and used to assess whether the target areas were observed to contain live green vegetation. The aspect and slope layers were constructed in ArcGIS 10.3 by surface analysis of the altitude layers at the same spatial scale. The layers were then converted to ASCII raster using the ArcMap 10.3 conversion tool for subsequent analysis in the MaxEnt model.

Modelling environmental suitability for ticks

MaxEnt software version 3.3.3 (48) was used to predict the appropriate ecological niches for the most important species of hard ticks collected from the study area. We considered 80% of the presence records for training the model and 20% for testing. The model was run ten times for each species. The contribution of the environmental variables was evaluated by Jackknife analysis.

Results

Collected species

In total, 2410 hard ticks were collected and recognized as *Hy. marginatum* (49.08%), *Hy. anatulicum* (15.26%), *Hy. asiaticum* (1.32 %), *Hy. excavatum* (0.53%), *Rh. bursa* (8.71 %), *Rh. turanicus* (22.11%), *Rh. sangineus* (2.24%), *Haemaphysalis parva* (0.53%) and *Ha. punctata* (0.16%). Species with wider distributions were considered for modelling.

Modelling ecological niches for dominant species

Hyalomma anatulicum

Twenty-nine and four available presence records of this tick species were randomly used as training and test points for the model, respectively. The average test area under the curve (AUC) was 0.848 with a standard deviation of 0.085. Table 1 presents the estimates of the relative contributions of environmental variables in the MaxEnt model. Figure 2 shows the point-wise mean of the ten output grids for these species. The red color shows areas with better-predicted conditions. According to the jackknife test of variable importance, the environmental variable with the greatest gain in the model was the mean diurnal range (Fig. 3). The response curve of *Hy. anatulicum* to this variable shows that the probability of the presence of this species decreased with an increase to about 102 and remained constant thereafter (Fig. 3).

Hyalomma asiaticum

Thirteen and two presence records were used as training and test points, respectively. The average test AUC was 0.762 with a standard deviation of 0.154. Table 1 shows estimates of the relative contributions of environmental variables to the MaxEnt model. Jackknife's analysis showed that the environmental variable with the greatest gain when used in isolation was the annual temperature (bio7). The probability of the presence of this species decreased with an increase in the temperature annual range (Fig. 3).

Hyalomma marginatum

Thirty-five and four presence records were used as training and test points, respectively. The average AUC was 0.812 with a standard deviation of 0.105. Table 1 shows estimates of the relative contributions of environmental variables to the MaxEnt model. The mean temperature of the coldest quarter (bio11) was the most effective variable in the model. The probability of the presence of this species increased from about 70 to 95 for this variable and then showed a slight decrease afterward (Fig. 3).

Rhipicephalus bursa

Thirty-three and four presence records were used as training and test points, respectively. The average AUC was 0.772 with a standard deviation of 0.120. Table 1 shows estimates of the relative contributions of the environmental variables to the MaxEnt model. Figure 4 shows the point-wise mean of ten output grids for these species. The red color indicates areas with better-predicted conditions. The Jackknife test of variable importance and the response of the ticks to the most effective bioclimatic variables is shown in Fig. 5. The most important variable in the model was the mean temperature of the coldest quarter (bio11). The probability of the presence of *Rh. bursa* increased from about 70 to 90 in this variable and showed a decrease thereafter (Fig. 5).

Rhipicephalus sanguineus

Fourteen and two presence records were used as training and test points, respectively. The average AUC was 0.770 with a standard deviation of 0.154. Table 2 shows the estimates of the relative contributions of environmental variables to the MaxEnt model. Figure 5 shows the results of the Jackknife test of variable importance. The most effective variable in the model was precipitation of the wettest month (bio13), so its' increase will provide better ecological niches for this species.

Rhipicephalus turanicus

Thirty-six and four presence records were used as training and test points. The average AUC was 0.803 with a standard deviation of 0.117. Table 1 shows estimates of the relative contributions of environmental variables to the MaxEnt model. Figure 5 shows the results of the Jackknife test of variable importance. The mean temperature of the coldest quarter (bio11) was the most effective variable in the model. An increase from about 70 to 90 in bio11 will provide suitable niches for this tick, while higher values cause a slight decrease thereafter (Fig. 5).

Table 1. Bioclimatic variables used for prediction distribution of hard ticks of veterinary importance in Golestan Province, Iran, 2014–2015

Variable	Definition	Species Contribution (%)					
		Hy. anatulicum	*Hy. asiaticum*	*Hy. marginatum*	*Rh. bursa*	*Rh. sanguineus*	*Rh. turanicus*
BIO1	Annual Mean Temperature (◦C)	2.5	0	1.9	6.3	0	1.9
BIO2	Mean diurnal Temperature range (mean of monthly max temp–min temp) (◦C)	9.4	2.7	3.2	0.3	0	1.7
BIO3	Isothermality (BIO2/BIO7) (×100)	2.3	0	0.2	0.5	0.9	0.5
BIO4	Temperature seasonality (standard deviation × 100)	1.4	19	1.9	3.2	4.7	2.2
BIO5	Max temperature of the warmest month (◦C)	3.8	0	4.8	5.2	0.2	4.2
BIO7	Temperature annual range (◦C)	1	3.2	1	0.8	0.1	0.4
BIO8	Mean temperature (◦C)	4.4	15.4	5.5	3.9	15.6	8.4
BIO9	Mean temperature of the driest quarter (◦C)	0	0	0	0	0.4	0
BIO10	Mean temperature of the warmest quarter (◦C)	0	0	0	0	0	0
BIO11	Mean temperature of the coldest quarter (◦C)	4.8	2.2	36.8	29.7	13.7	35.7
BIO12	Annual precipitation (mm)	1.2	3.1	0.7	1.3	1.3	0.9
BIO13	Precipitation of the wettest month (mm)	0.4	0.2	0.9	0.4	24.3	0.3
BIO14	Precipitation of the driest month (mm)	2	5.6	0.2	0.5	0.4	0.3
BIO15	Seasonal precipitation (coefficient of variation)	1.1	5.3	0.3	0.9	3	0.9
BIO16	Precipitation of the wettest quarter (mm)	0.1	0.2	0.3	0.6	15.9	0.5
BIO17	Precipitation of the driest quarter (mm)	43.8	16.4	25.4	25.5	0.4	25.2
BIO18	Precipitation of the warmest quarter (mm)	0.7	23.3	3	12.1	12.6	5.8
BIO19	Precipitation of the coldest quarter (mm)	0.2	0.5	0.4	0.2	0.6	1
Altitude	Elevation from the sea level (m)	8.1	0	1.6	1.6	1.2	1.6
Aspect	Direction of slope	2.8	0.1	2.4	1	2.2	2
Slope	Slope of the area (Degree)	9.9	2.6	9	5.7	2.6	6.3
NDVI	Normalized difference vegetation index (-1 to +1)	0.1	0	0.4	0.3	0	0.1

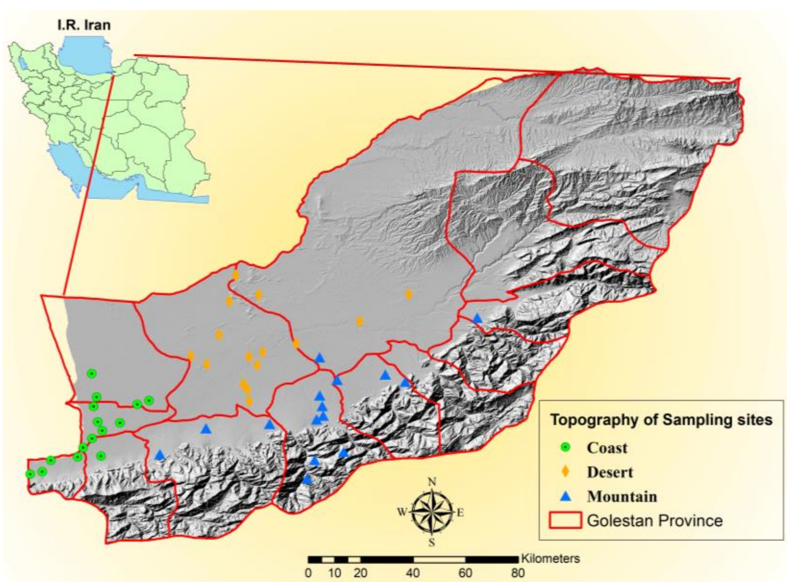

Fig. 1. Hard tick sampling locations in Golestan Province, Iran, 2014–2015

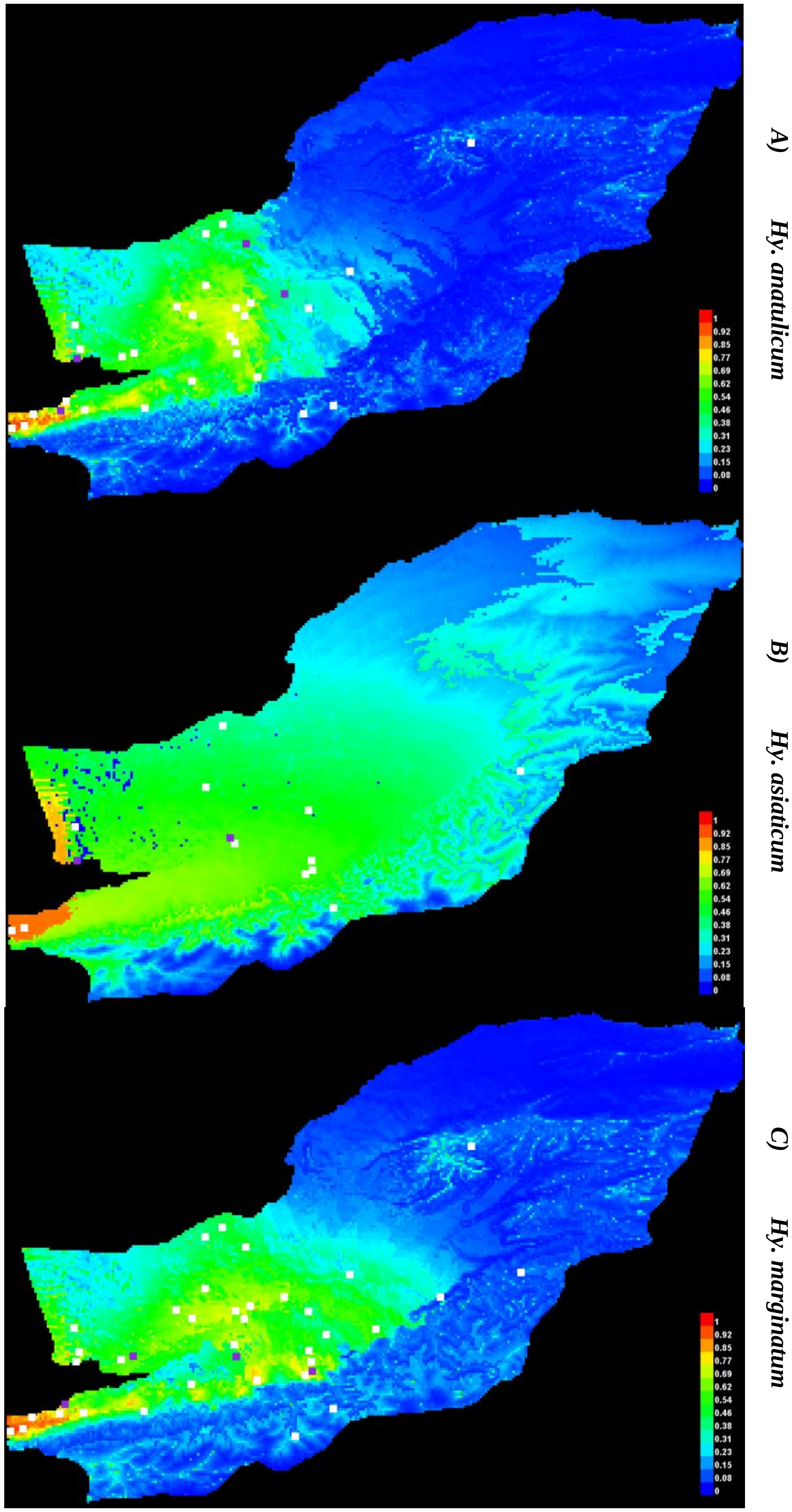

Fig. 2. Probability of presence for *Hy. anatulicum*, *Hy. asiaticum* and *Hy marginatum* in Golestan Province using the MaxEnt model, Iran, 2014-2015. The probability range is between 0 (Blue color) and 1 (Red color)

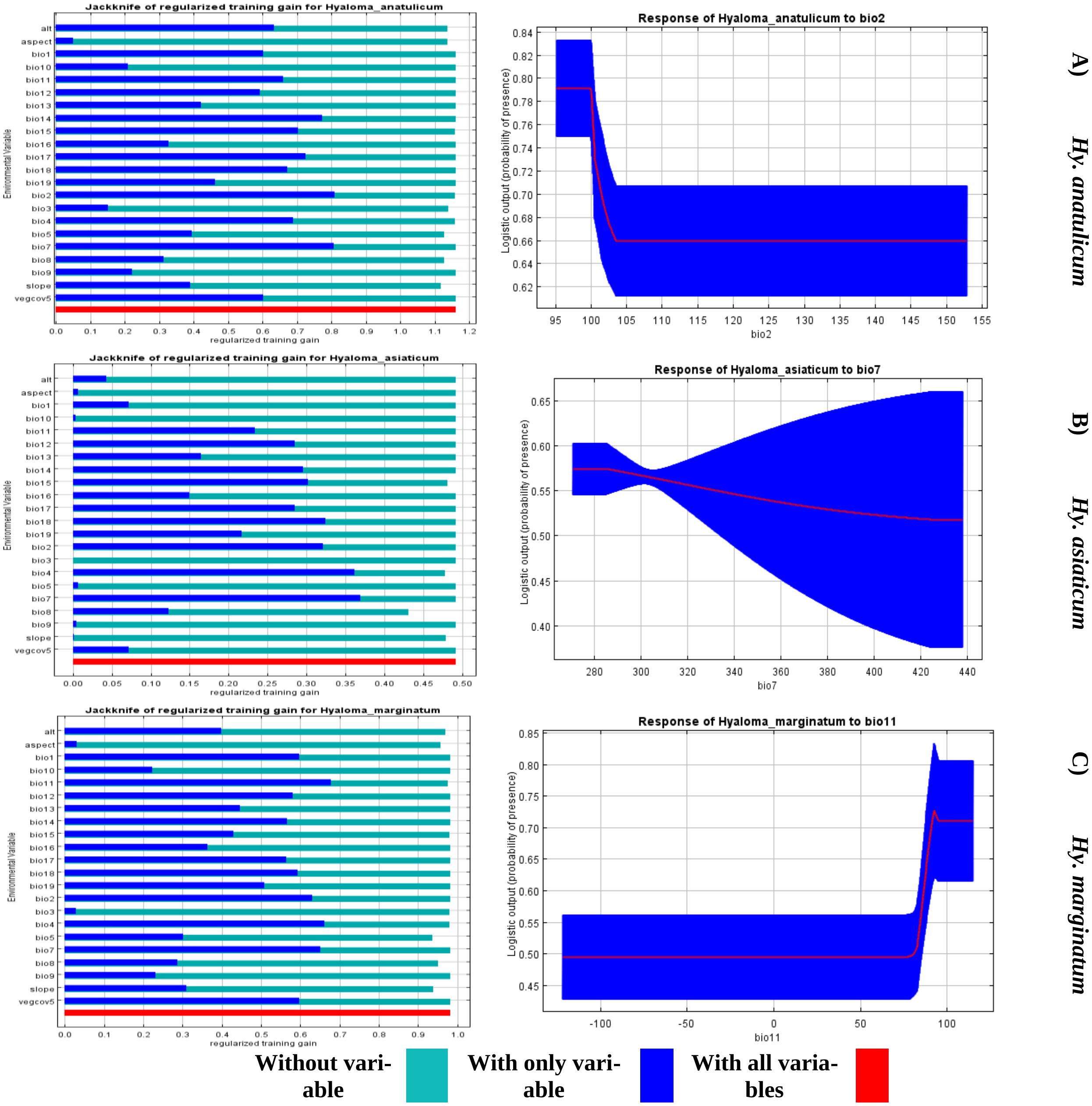

Fig. 3. Jackknife of regularized training gain for *Hy. anatulicum*, *Hy. asiaticum* and *Hy. marginatum* . Left panel: X: regularized training gain (0-1) and Y: environmental variable, and right panel: the response of the three species to the most effective bioclimatic variables (see table 1), X: response and Y: logistic output (probability of presence)

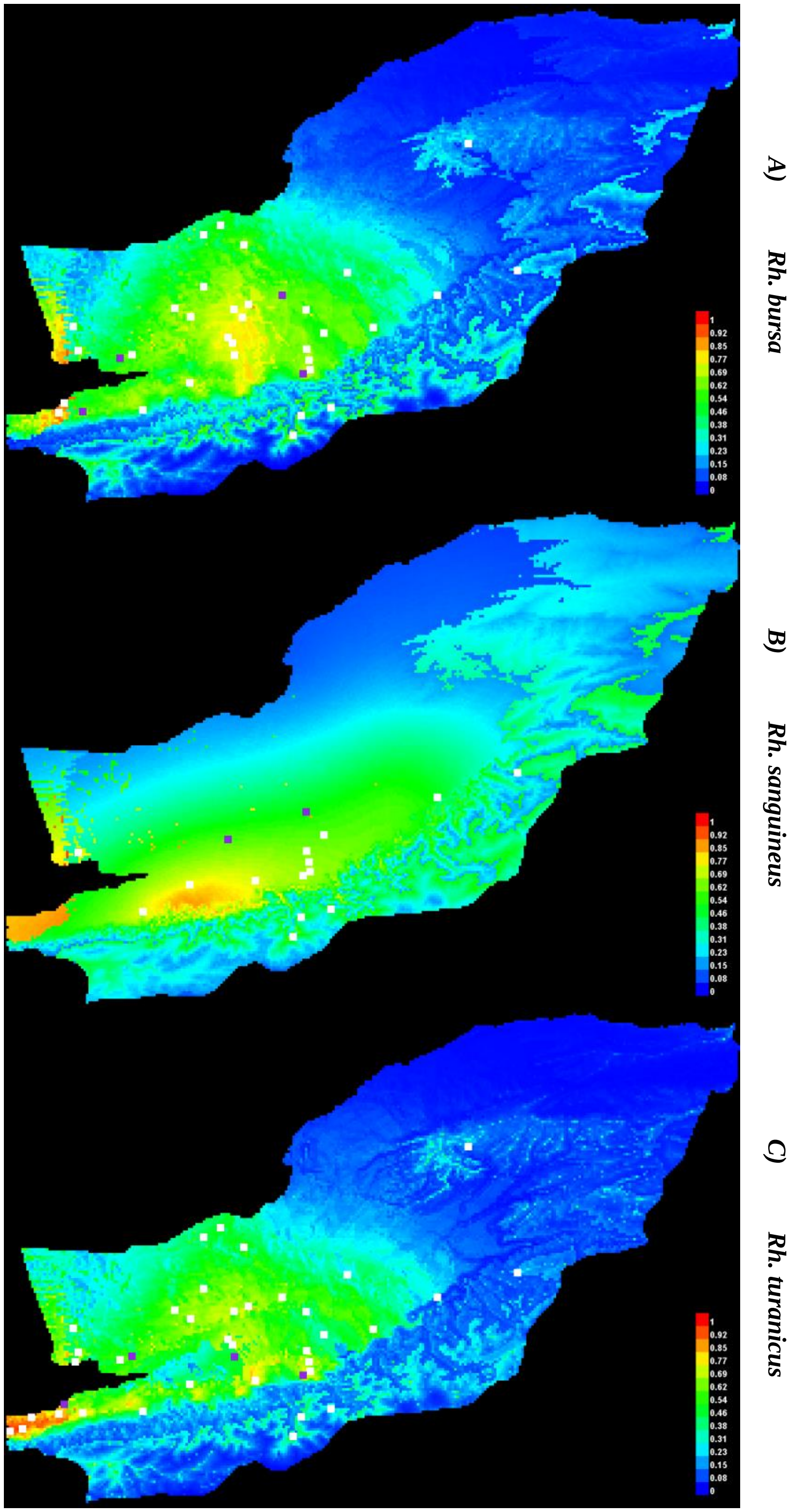

Fig. 4. Probability of presence for *Rhipicephalus bursa*, *Rh. sanguineus* and *Rh. turanicus* in Golestan Province, Iran, 2014–2015. The probability range is between 0 (Blue color) and 1 (Red color)

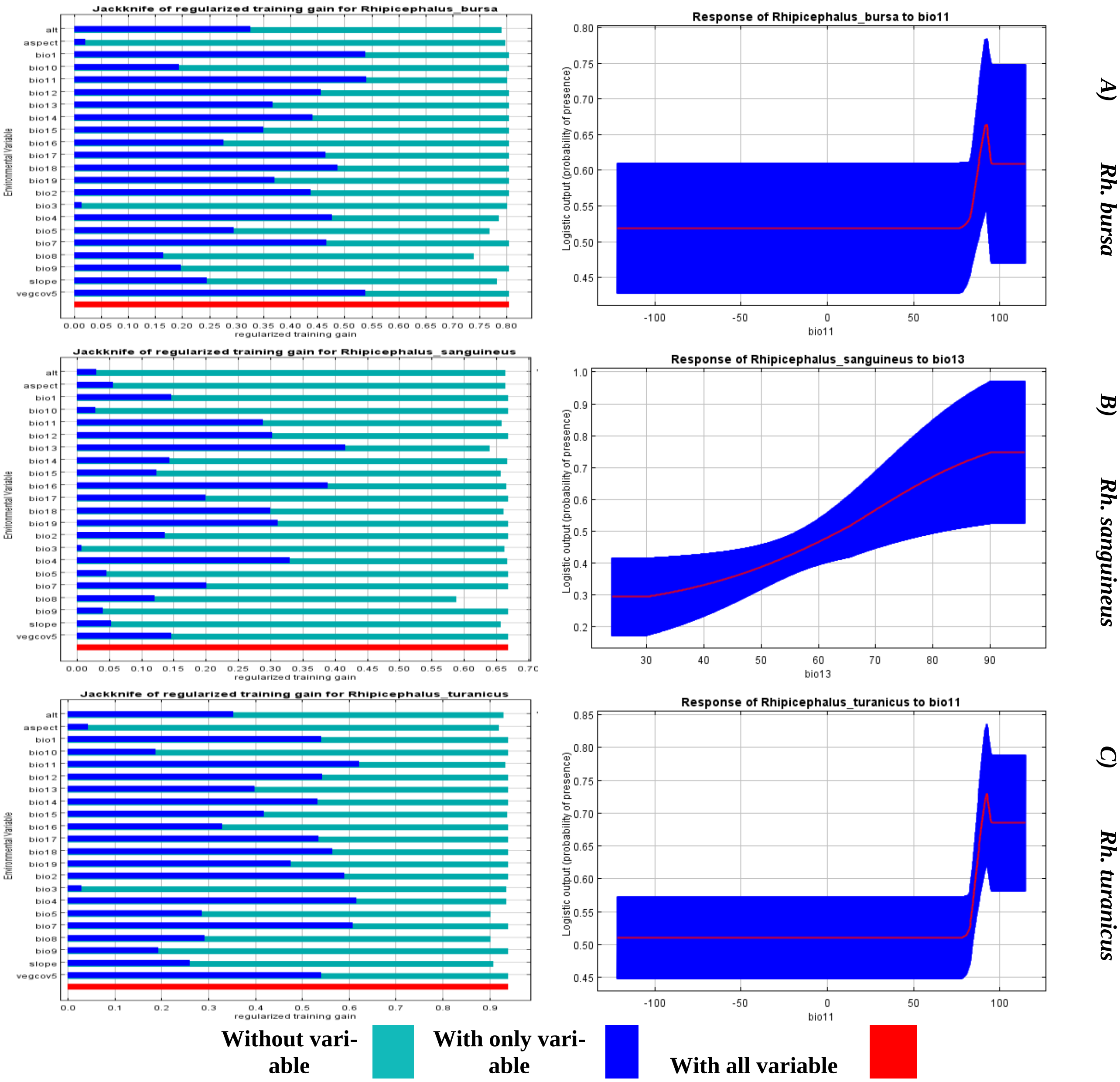

Fig. 5. Jackknife analysis of regularized training gain for *Rh. bursa*, *Rh. sanguineus* and *Rh. Turanicus.* Left panel: X: regularized training gain and Y: environmental variable, and right panel: response of the three species to the most effective bioclimatic variable (see Table 1), X: Response Y: logistic output (probability of presence)

Discussion

This study was undertaken to predict suitable environmental conditions for the dominant hard tick species of veterinary importance in Golestan Province using the prediction models based on climate data. In this study, 18 bioclimatic and four environmental variables were used for modelling. This approach has been used for ticks by other researchers (49−51). The best niches for almost all ticks in this study generally were in the western part of Golestan Province. This is an area primarily covered by lowland plains that are suitable for grazing sheep. An earlier study reported a higher density and greater species diversity of ticks in this region (52).

The distribution range of ticks is influenced by complex interactions of both biotic (prevailing types of vegetation, host specificity, host community structure, and abundance) and abiotic, climatic factors. Data about tick distribution is needed to protect against future threats and for the formulation of an adequate epidemiological policy regarding ticks (53).

Hy. marginatum, that infests livestock in areas with a humid Mediterranean climate, is a notorious vector of the CCHF virus (8). Seasonal conditions and geographic location are two important factors that can affect tick behaviour for host selection (8).

Several studies have confirmed that *Hy. marginatum* is widely distributed across the entire zoographical zone of Iran, followed by *Hy. anatulicum* (20, 54). The best ecological niches for *Hy. marginatum* was detected in the western part of Golestan Province, while *Hy. anatulicum* was found from the east to the central areas of the province. It is thus expected that the likelihood of livestock infestation by this tick and the risk of transmission of parasitic diseases to these animals is great in this area.

Hyalomma asiaticum was described by Schulze in 1930 as a problematic species of the genus *Hyalomma*. Nabian et al. (2009) reported that *Hy. asiaticum* has been found in all zoogeographic zones in Iran. Experiments have shown that *Hy. asiaticum* can transmit the protozoan agent of bovine theileriosis, *T. annulata*, in Iran. However, its role in nature has been neglected (19). Two strains of Wanowrie virus have been isolated from *Hy. asiaticum* specimens collected in Iran (55). The favorite niches for this tick were predicted to be in the western part of Golestan Province and extend to the central regions.

Rhipicephalus ticks are the most important tick species afflicting sheep flocks in Iran. *Rhipicephalus bursa* is a common species in livestock, and it transmits protozoans and bacteria. This tick is found in Mediterranean climatic regions in the Mediterranean basins and along the Black and Caspian Seas (8). In Iran, *Rh. bursa* is the dominant sheep tick in the Zagros Mountains, but could not be found in semi-desert areas and around the Persian Gulf (56). Hosseini et al. (2010) found this species in very small numbers in the city of Ghaemshahr in Mazandaran Province (57). Ebrahimzadeh et al. (2014) reported the frequency of this tick to be 24.66% in Mazandaran Province in northern Iran. The prediction map showed habitat suitability for this species is the best in the western part of Golestan Province (58).

Rhipicephalus turanicus has been designated as a minor tick parasite on sheep and is mainly found in northern and north-western areas of Iran (59). Razmi et al. (2011) reported that *Rh. turanicus* had the highest frequency in the northern and southern parts of Khorassan-e Razavi Province (34). Nabian and Rahbari (2007) identified *Rh. turanicus* as a rare species in the Zagros Mountain areas. Sharifdini et al. (2021) were found *Rh. turanicus* on raccoons for the first time in Guilan Province (45). The output of the MaxEnt model showed that this species prefers the western parts of Golestan province (40).

The primary host of *Rh. sanguineus* is domestic dog, but it also can be found on other hosts, including cattle, sheep, goats, and humans. This species has been found in Guilan Province from raccoons (45). In Iran, *Rh. sanguineus* is a major species in the northern (Caspian Sea) and semi-desert areas (59). The prediction map shows habitat suitability for this species is more extensive than for other species, such that it can breed in the east, south, and center of Golestan Province.

The AUCs were acceptable for all the species used for modelling and were higher than 0.7, which indicates the good performance of our model (60). From the results obtained from the model output, as well as jackknife analysis, it was found that the mean temperature of the wettest quarter usually has the most significant effect on the distribution of *Rhipicephalus* spp. when removed from the model.

While other tick models have used effective factors for their distributions, this issue is an underlying factor for the presence of different species of ticks in certain seasons and weather conditions throughout the year. Several studies have been conducted in this regard, and in each of these studies, important factors affecting the distribution of ticks have been reported for the different geographical areas. A study conducted in Romania reported that the mean temperature of the coldest quarter for *Hy. marginatum* and precipitation of the warmest quarter for *Rh. annulatus* were the most critical variables affecting the distribution of these ticks (50). Another study in 2018 modelled different locations for collecting *Rhipicephalus* spp. between 1970 and 2017 in Mexico. Precipitation seasonality, particularly in March, and isothermality were found to be the most significant climate variables for determining the probability of spatial distribution for this tick (51). In a study conducted to determine the most suitable habitat for *Rh. appendiculatus* in the Horn of Africa, the annual temperature range, temperature seasonality, and annual precipitation were listed as important predictor variables. The most suitable habitat for *Rh. appendiculatus* was predicted to have high precipitation and moderate temperature values (61).

Output models obtained from MaxEnt indicate that the western and north-western regions of the province are the most suitable habitats for different species of ticks. In a previous study by Farahi et al. 2016 (52), the number of ticks reported on the west coast of the province of Golestan was greater than in other areas. In their study, the most diverse species of ticks collected were found in the plains and hillside regions of the province, which are located in the northern and south-western parts of the province.

Regarding the advantages of using the MaxEnt model for prediction of habitat suitability for tick, it can be said that the prediction accuracy is always reliable, even with a small sample size. Also, this model only needs the presence data of the target species, so it is easy to use. However, considering that in most studies on ticks, sampling is done from livestock herds and other methods of direct capture of ticks from pastures and the environment are not done due to the problems it has, it is possible that the presence points that are included in the model do not match the reality to some extent. Despite this, it can be justified that the contamination of the sampled livestock depends on the contamination of the pastures that the livestock graze on. These items can be considered as disadvantages of using the MaxEnt model for predicting the habitat suitability for ticks.

Conclusion

The output of the MaxEnt models indicates that the western and south-western regions of Golestan Province provide the best niches for the presence of ticks. Therefore, it seems these parts of the province are desirable potential habitats for the presence of tick-borne diseases in both livestock and humans. Attention should be focused on preventing the spread of diseases in these regions.

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Ethical consideration

The project was conducted according to the ethical principles and the national norms and standards for conducting Research at the University of Tehran, Iran. The project number was (95.7.13:681).

Conflict of interest statement

The authors declare there is no conflict of interest.

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